ASCENT Project 54

AEDT Evaluation and Development Support

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Cost Share Partner: Delta Air Lines

Objective:

- Provide data and methods to continue to improve aircraft weight, takeoff thrust, and departure and arrival procedure modeling capabilities within AEDT
- Utilize real-world flight data to improve departure, full flight, and arrival modeling
- Conduct system evaluation of newly implemented AEDT features

Project Benefits:

- Address gaps in AEDT's modeling assumptions to improve accuracy of environmental metrics, i.e., noise, fuel burn, emissions and air quality impacts.
- Enhance AEDT by providing additional modeling options for LTO and enroute operations based on real-world flight data

Research Approach:

- Perform comparisons between millions of real-world flights against the outputs of AEDT's performance models for arrival, departure, and enroute phases to obtain statistics about the overall agreement with existing AEDT definitions
- Use obtained statistics and modeling results to provide recommendations on improving the accuracy of AEDT modeling capabilities
- Perform system testing and evaluation of AEDT features to identify discrepancies, quantify differences, and document possible improvements for future efforts

Major Accomplishments (to date):

- Compared AEDT profiles to real-world operations for arrivals & departures to identify key differences
- Developed method for comparing full flight model in AEDT against actual airline FOQA data.
- Performed system testing on various AEDT features and made recommendations

Future Work / Schedule:

- Develop recommendations for new departure and arrival procedural profiles to be implemented in AEDT
- Complete comparison of full-flight modeling in AEDT with real-world flight operations
- Continue support for future AEDT development

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Project structure

Project is comprised of two main research themes:

ASCENT 54

Aircraft Performance Modeling

- Improve the accuracy of modeling in AEDT across all flight phases to better represent real aircraft operations
- The improvements to AEDT will support airport noise compatibility programs and planning with more accurate results to better inform federal financial support of those programs
- This task addresses improvements and comparisons to real-world operations for arrival, departure, and full-flight modeling options in AEDT

Uncertainty Quantification

- Perform system testing to evaluate the accuracy, functionality, and capabilities of AEDT and support the future development process
- Identify gaps in the tool's functionality and areas for further research and development
- Document new AEDT features and their effect on metric results in the form of a UQ report

Outline of Presentation

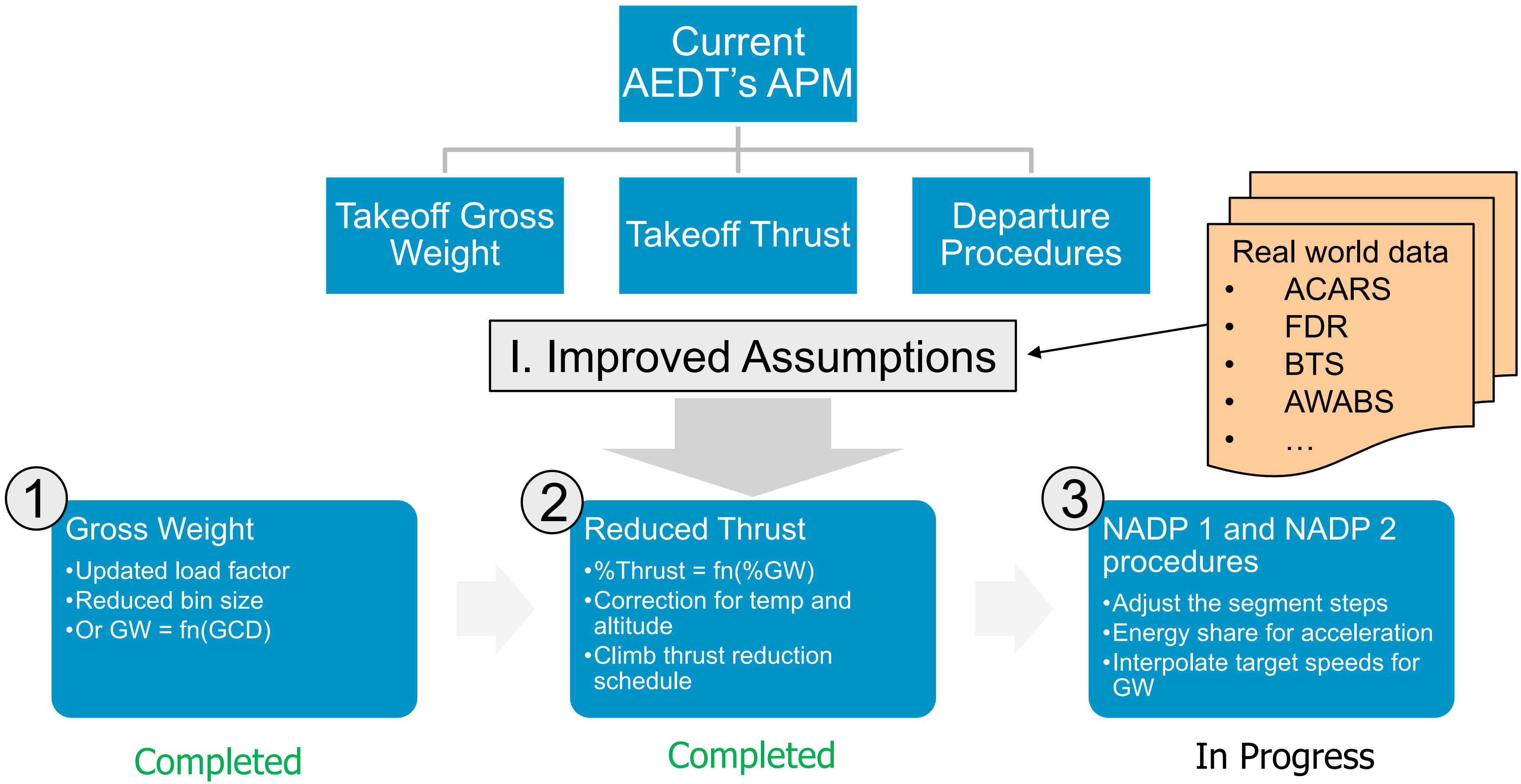
Presentation organized by research themes

1. Departure Modeling updates
2. Arrival Modeling updates
    1. NPD+C updates
3. Full Flight Modeling updates
4. Supersonic Modeling updates
5. Uncertainty Quantification updates

Departure Modeling – Introduction

- Accurate modeling of aircraft performance is a key factor in estimating aircraft noise, emissions and fuel burn
- Various assumptions are made for aircraft performance modeling (APM) within the AEDT with respect to:
  - Takeoff weight
  - Takeoff thrust
  - Departure flight profiles
- The main objectives of this research are to
  1. Benchmark the current APM assumptions against real-world performance data
  2. Document recommendations for APM enhancements

Departure Modeling – Improving AEDT's Assumptions



APM	Aircraft Performance Module	AWABS	Aircraft Weight and Balance System
ACARS	Aircraft Communications Addressing and Reporting System	GW	Gross Weight
FDR	Flight Data Recorder	GCD	Great Circle Distance
BTS	Bureau of Transportation Statistics	NADP	Noise Abatement Departure Procedure

Reduced Thrust and Alternative Weight Profiles

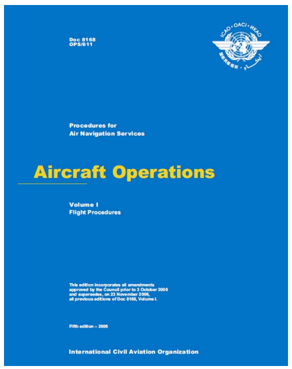
- Developed new profiles for 90 commercial and business jet aircraft
- Each aircraft have 7 additional sets of profiles populated in the FLEET DB
- The new **alternative** weight of a stage length is the average of current stage length (SL) weight and the weight of the immediate next SL
- The reduced takeoff thrust is implemented via a multiplication of the full thrust coefficients by the reduction percentage

PROF_ID1	Weight	Takeoff Thrust Level	Climb Thrust Level
STANDARD	Standard Weight	0% Reduction	0% Reduction
MODIFIED_RT05	Standard Weight	5% Reduction	0% Reduction
MODIFIED_RT10	Standard Weight	10% Reduction	10% Reduction
MODIFIED_RT15	Standard Weight	15% Reduction	10% Reduction
MODIFIED_AW	Alternative Weight	0% Reduction	0% Reduction
MODIFIED_AW_RT05	Alternative Weight	5% Reduction	0% Reduction
MODIFIED_AW_RT10	Alternative Weight	10% Reduction	10% Reduction
MODIFIED_AW_RT15	Alternative Weight	15% Reduction	10% Reduction

Note: FAA AEE approval is required in order to use the modified profiles for regulatory applications. Users must submit a justification for the profile they select.

Noise Abatement Departure Procedures (NADPs)

ICAO and FAA recommend that all carriers adopt no more than two procedures for each aircraft type; one for noise abatement of communities close to the airport and one for noise abatement of communities far from the airport


Doc 8168
OPS/611

Procedures for
Air Navigation Services

Aircraft Operations

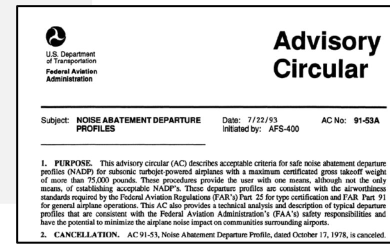
Volume I
Flight Procedures

This edition incorporates all amendments approved by the Council prior to 3 October 2006 and supersedes, on 23 November 2006, all previous editions of Doc 8168, Volume I.

Fifth edition – 2006

International Civil Aviation Organization

Terminology	ICAO / FAA Documents
ICAO-A & ICAO-B (OBSOLETE)	ICAO, Procedures for Air Navigation Services (PANS-OPS) Volume I
Close-in & Distant	FAA, AC91-53A, 1993
NADP1 & NADP2	ICAO, PANS-OPS Volume I, 2006

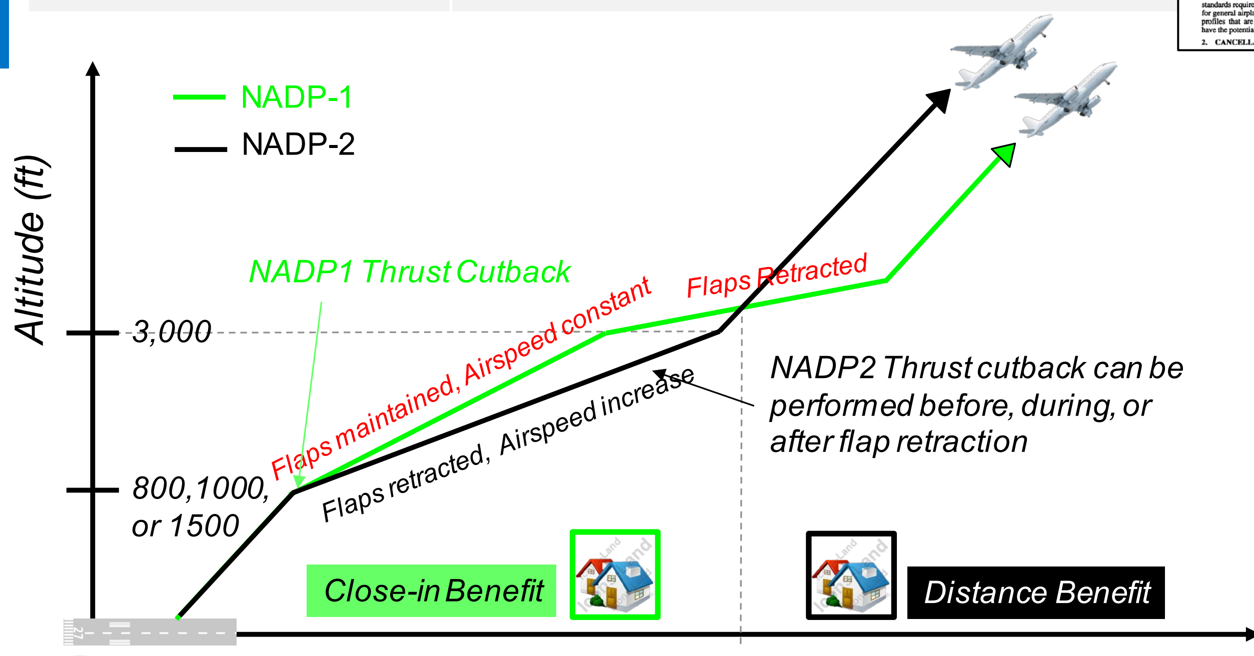

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: **NOISE ABATEMENT DEPARTURE PROFILES** Date: 7/22/93 Initiated by: AFS-400 AC No: **91-53A**

1. **PURPOSE.** This advisory circular (AC) describes acceptable criteria for safe noise abatement departure profiles (NADP) for subsonic turbojet-powered airplanes with a maximum certificated gross takeoff weight of more than 75,000 pounds. These procedures provide the user with one means, although not the only means, of establishing acceptable NADP's. These departure profiles are consistent with the airworthiness standards required by the Federal Aviation Regulations (FAR's) Part 25 for type certification and FAR Part 91 for general airplane operations. This AC also provides a technical analysis and description of typical departure profiles that are consistent with the Federal Aviation Administration's (FAA's) safety responsibilities and have the potential to minimize the airplane noise impact on communities surrounding airports.

2. **CANCELLATION.** AC 91-53, Noise Abatement Departure Profile, dated October 17, 1978, is canceled.



Graphics adopted from ACRP 02-12 Report 86

Departure Modeling – Objective

- Based on previous research, it was recommended that two NADP profiles be implemented in AEDT
  - One for close-in another for distant noise benefit

Candidate NADP profiles selected for further analysis

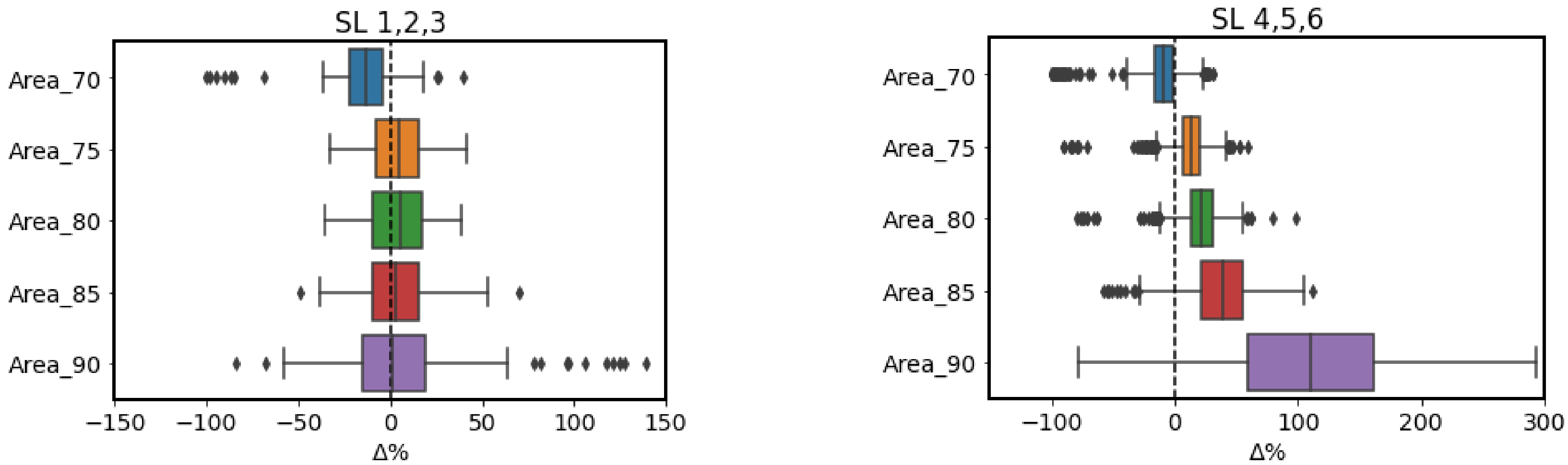
Profile Name	Noise benefit	Thrust Cutback	Acceleration initiation altitude	Final acceleration altitude
NADP1-1	Close-in	800 ft	1500 ft	3000 ft
NADP2-11	Distant	After acceleration	1000 ft	3000 ft

- **Current Objective**: Determine how representative subsets of the recommended NADP profiles in AEDT are to real world procedures
  - Determine noise abatement effectiveness on an airport level using DNL to account for large number of operations that take place per day
  - Quantify differences between recommended NAPD profiles to the STANDARD profile

Departure Modeling – Recap

- **Previous Work**: Analyze noise abatement of individual flights using SEL contours
  - Focus on noise contour differences between NADP2_11 and FPP (Fixed-Point Profile)

Differences in Contour Area with Real World Flights (FPP minus NADP2_11_AW_RT15)



- Quantified differences between FPP (real-world data) and NADP at airport averaged weather conditions
  - Real-world flights produced shorter and wider contours, net effect of higher contour area for 75 dB and above
  - Real world flights with higher stage lengths (SL) tend to use less thrust reduction – leads to differences for the SL 4, 5, and 6 plots when compared to the NADP profile which uses 15% thrust reduction
- **Current Approach**: Move to an airport-level analysis to be more representative of the real world

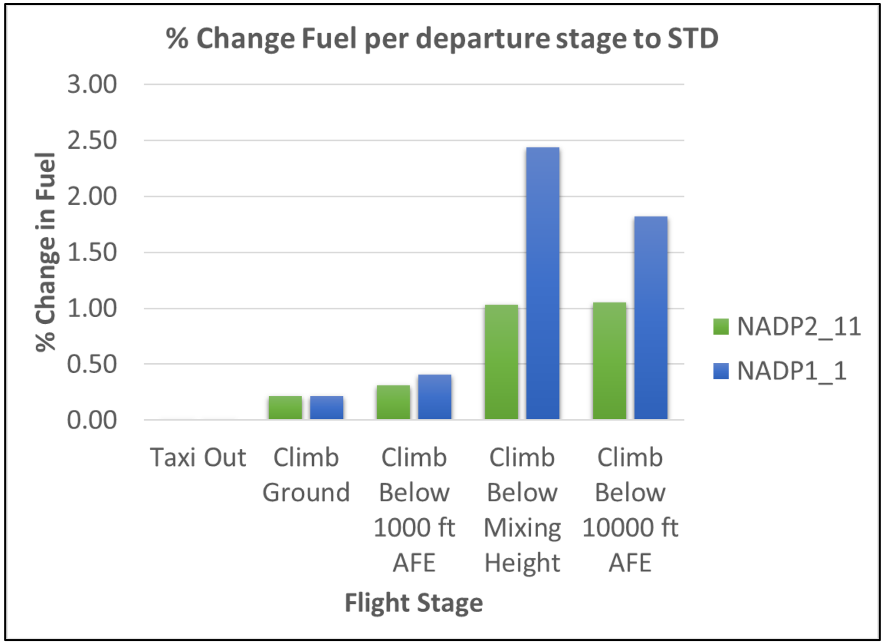
Departure Modeling – Current Approach

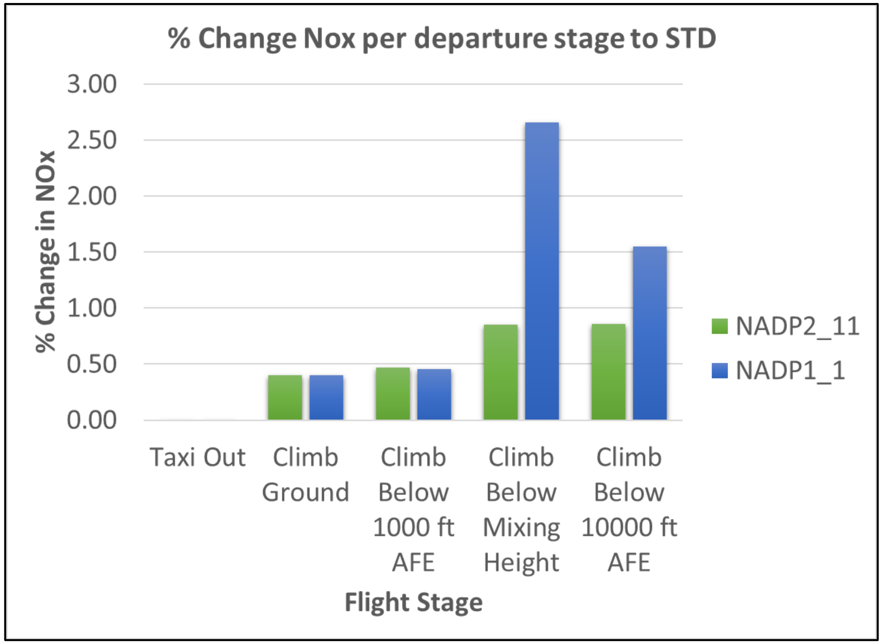
- **Approach**: Model departures using NADP and STANDARD profiles and quantify differences in noise, emissions, and fuel consumption
  - Representative Aircraft: Airbus A320, Boeing 717-200, Boeing 737-700, Boeing 737-800, CRJ9-ER, MD-82
    - Together covers around 80% of total operations
  - Test Case: Hartsfield-Jackson International Airport (KATL)
    - Straight departure headed east
  - Weather: Averaged weather for the airport
  - Performance Model: ANP

STANDARD	NADP1_1	NADP2_11
• Baseline profile used for comparing NADP effectiveness	• Attempts to minimize noise close to the airport (close-in) • Performs cutback earlier	• Attempts to minimize noise further away from the airport (far-out) • Performs cutback later

Departure Modeling

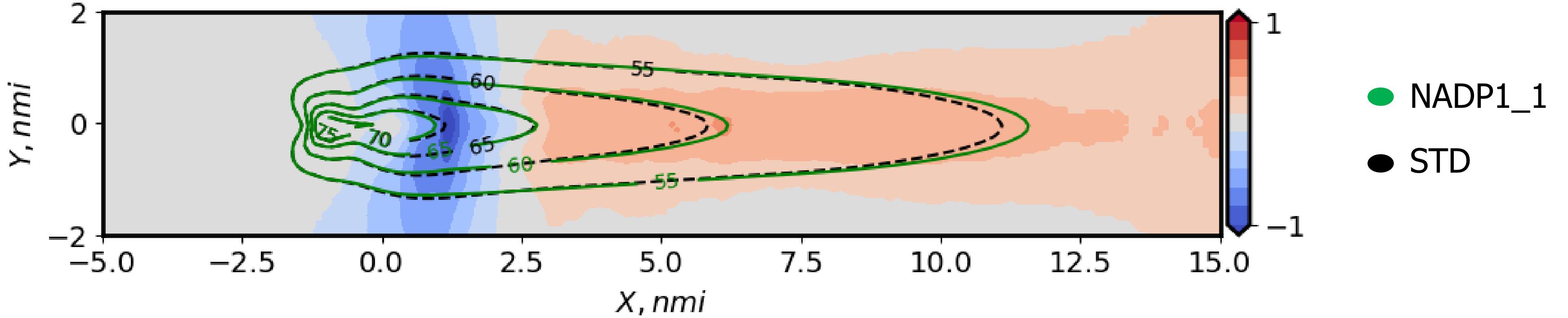
- Fuel consumption & NO_x Emissions
  - Increased fuel consumption compared to STD in both profiles
  - NADP1_1 has slightly smaller consumption during low altitude flight – much higher consumption afterwards
  - Correlates to the idea of reduced engine usage at low altitude



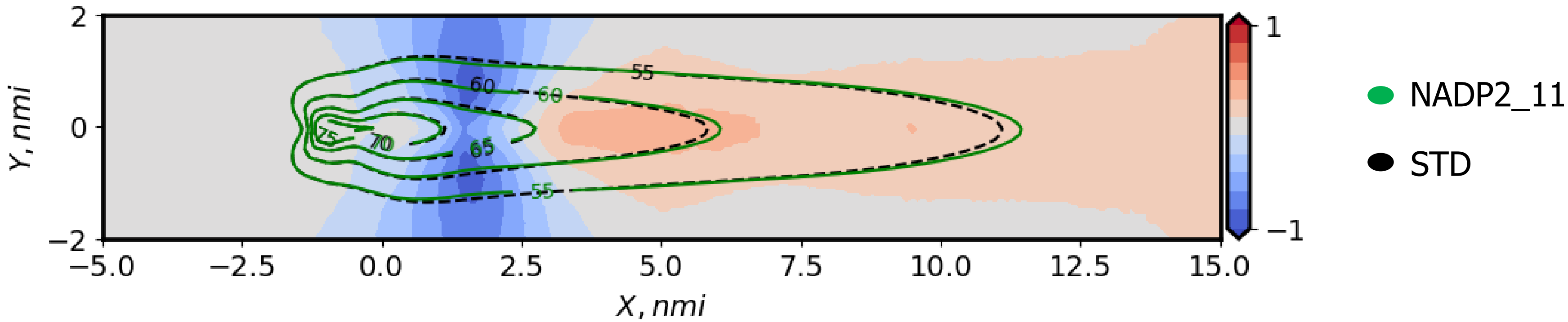


Departure Modeling

Difference in DNL between STD and NADP1_1



Difference in DNL between STD and



- Both NADPs have more noise further away from the airport along the flight path compared to STD, but the magnitude of noise overall is much less at those faraway points, leading to larger, low-noise contours
- NADP 2_11 has less noise in the direct flight path and around the airport, but NADP1_1 reduces noise the most directly at the tail end of the 60 dB and 70 dB contours

Departure Modeling

DNL Contour Metrics

Metric	Area (nmi^2)	Length (nmi)	Width (nmi)
55 dB	23.31 / 24.04 / 23.61	12.70 / 13.17 / 13.04	2.60 / 2.49 / 2.51
65 dB	3.09 / 2.92 / 2.90	4.00 / 4.05 / 4.02	1.09 / 1.03 / 1.06
75 dB	0.14 / 0.15 / 0.15	0.97 / 0.97 / 0.97	0.30 / 0.30 / 0.30

Metric Percentage Changes Relative to STANDARD

Metric	% Change Area	% Change Length	% Change Width
55 dB	3.13 / 1.29	3.70 / 2.67	-4.23 / -3.46
65 dB	-5.50 / -6.15	1.25 / 0.5	-5.50 / -2.75
75 dB	7.14 / 7.14	0 / 0	0 / 0

STANDARD
NADP1_1
NADP2_11

- Both profiles significantly reduce the area of the 65 dB contour
- Both profiles increase the size of the 75 dB contour, but the contour itself is very small

Next Steps:

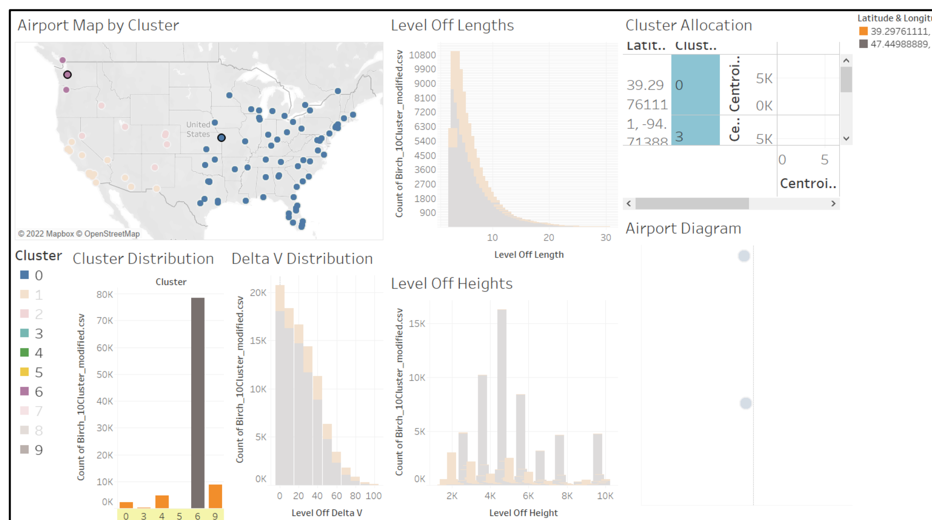
- Utilize new 2021 threaded track data to confirm and update departure NADPs
- Revisit airport-level analysis with more parameters to check fit, e.g., weather & compare to noise inventory studies

Arrival Modeling

- **Objective**: To find and develop recommendations for AEDT that will allow it to better capture aircraft behavior during arrival
  - Accurately capture the arrival of aircraft at airports based on real-world data
  - Enhance the ability of AEDT to model aircraft approaches and classify them as one of several arrival profiles suggested by the analysis of real-life data
- **Approach**:
  - Model arrival profiles obtained from clusters in AEDT to assess the sensitivities of environmental metrics to level-off parameters

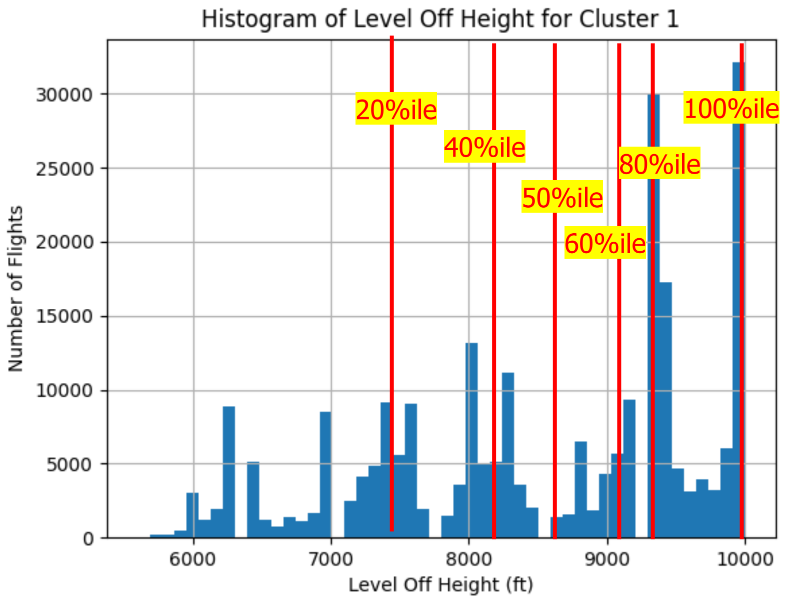
Arrival Modeling – Previous Work

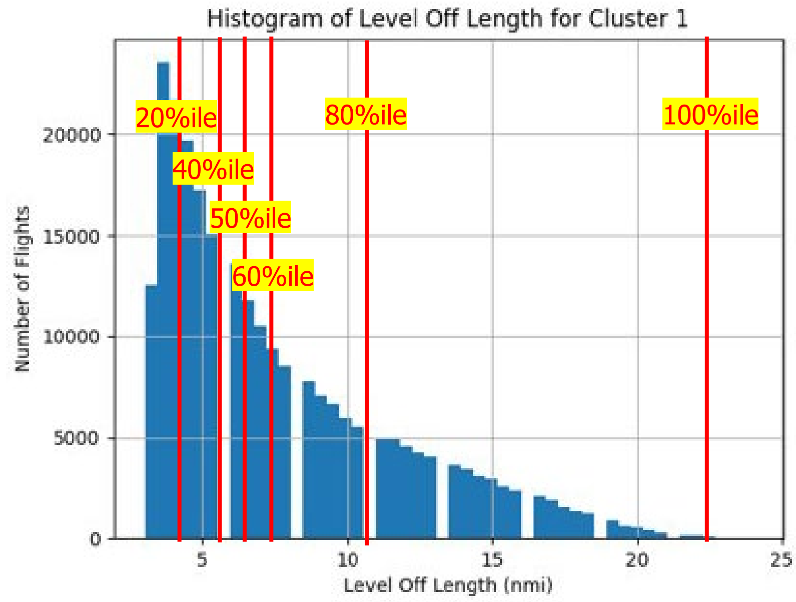
- Previously we had clustered flights into groups of similar level-off arrival operations (10 clusters)
  - Clustering was carried out to reduce the number of data points by finding logical groupings
  - The data set that was used for this project was the aircraft approach data from 95 airports with 2,786,015 flights provided as part of the 2019 Threaded Track Analysis
  - K-means and BIRCH algorithms produced the best results upon testing
- Each level-off (LO) arrival was characterized by the level-off parameters
  - LO height, LO distance, and LO speed change



Arrival Modeling – Current Work

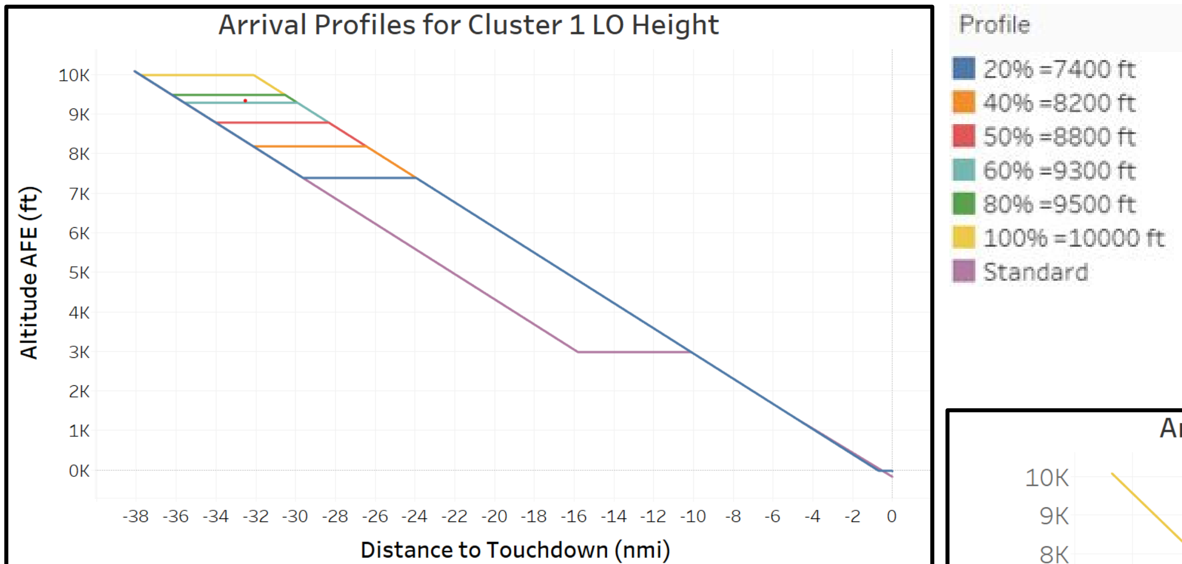
- We model 5 percentile values, in addition to the median
  - This maintains a reasonable level of modeling effort required
  - Using percentile values structures the sampling of parameter values
  - Comparison of the environmental metric results gives more insight
- Modeling of Cluster 1
  - Cluster 1 consists of 248,575 flights and is characterized by flights having higher level-off heights
  - Modeling is performed on the ORD airport with Boeing 737-800 as it is the airport with maximum flights (51,926) of cluster 1

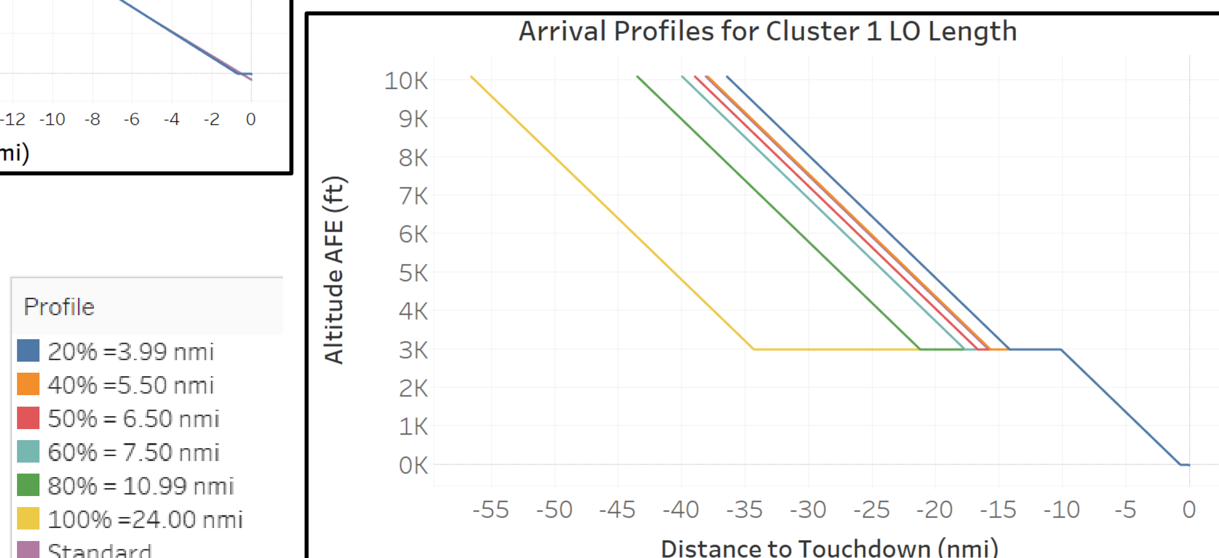




Arrival Modeling – Modeling results

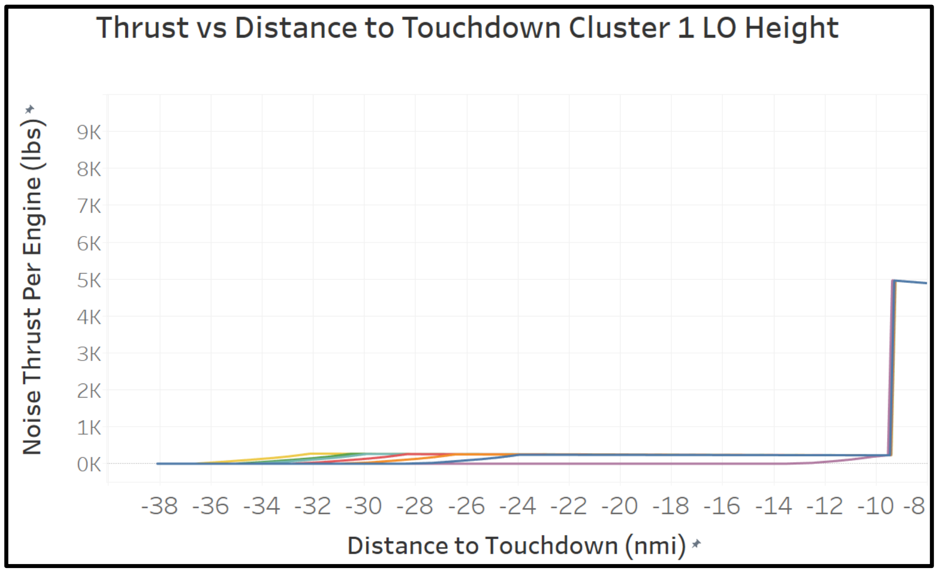
- For understanding influence of these range of level-off parameters on environmental metrics, level-off heights are kept constant while modeling Level-off length profiles and vice-versa

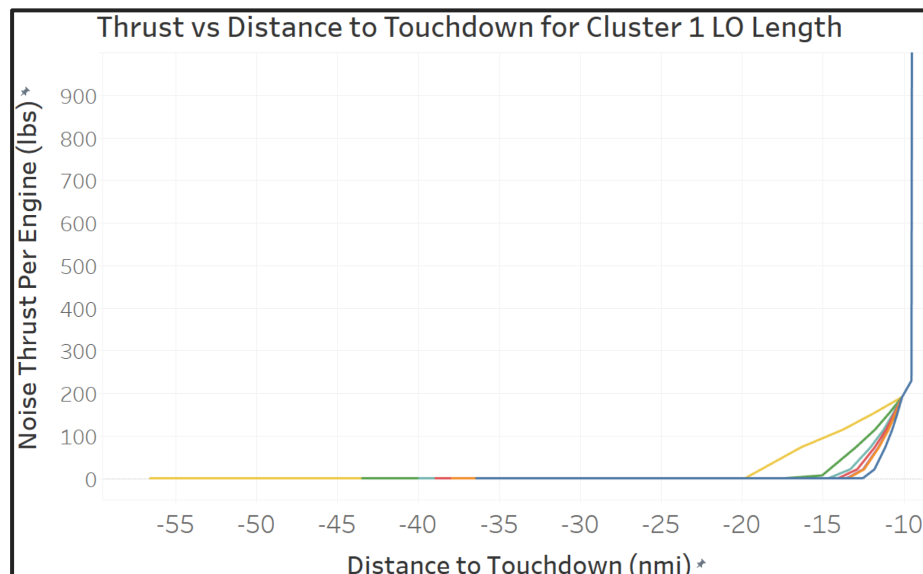




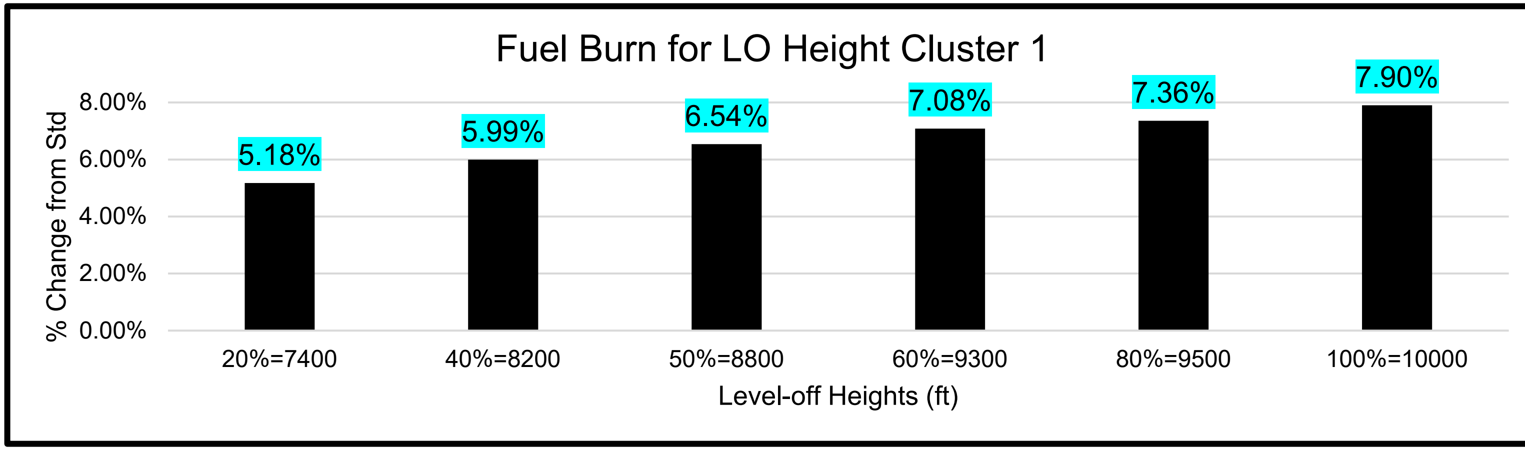
Arrival Modeling – Thrust variation

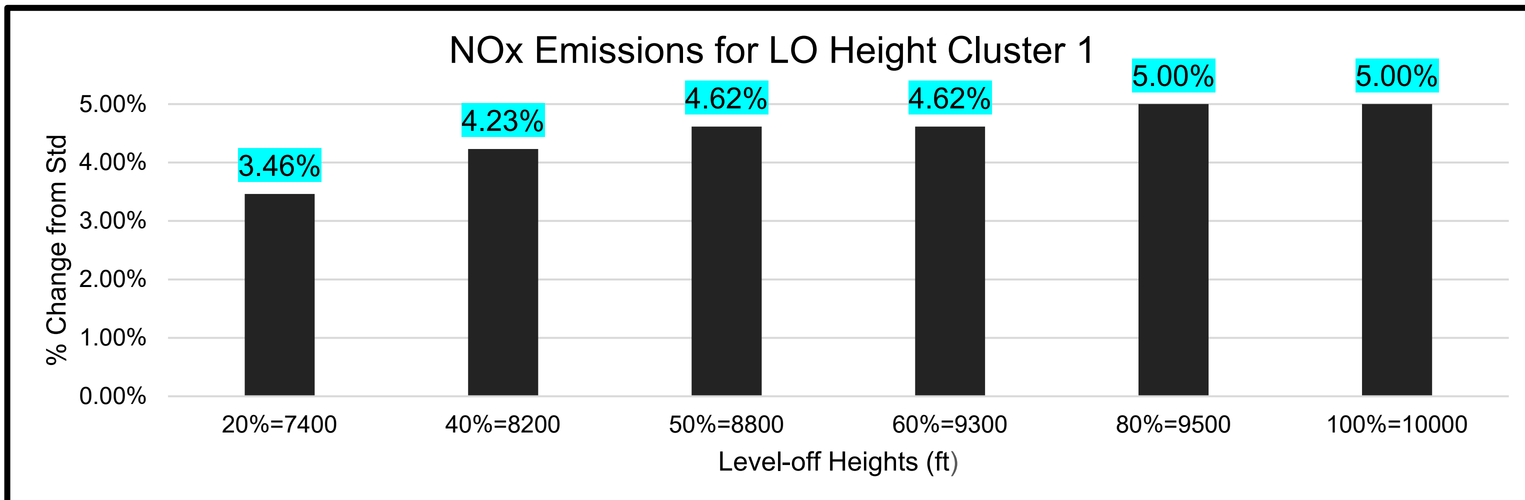
- Minor differences in thrust variation were observed, with the location of change in thrust varying across profiles





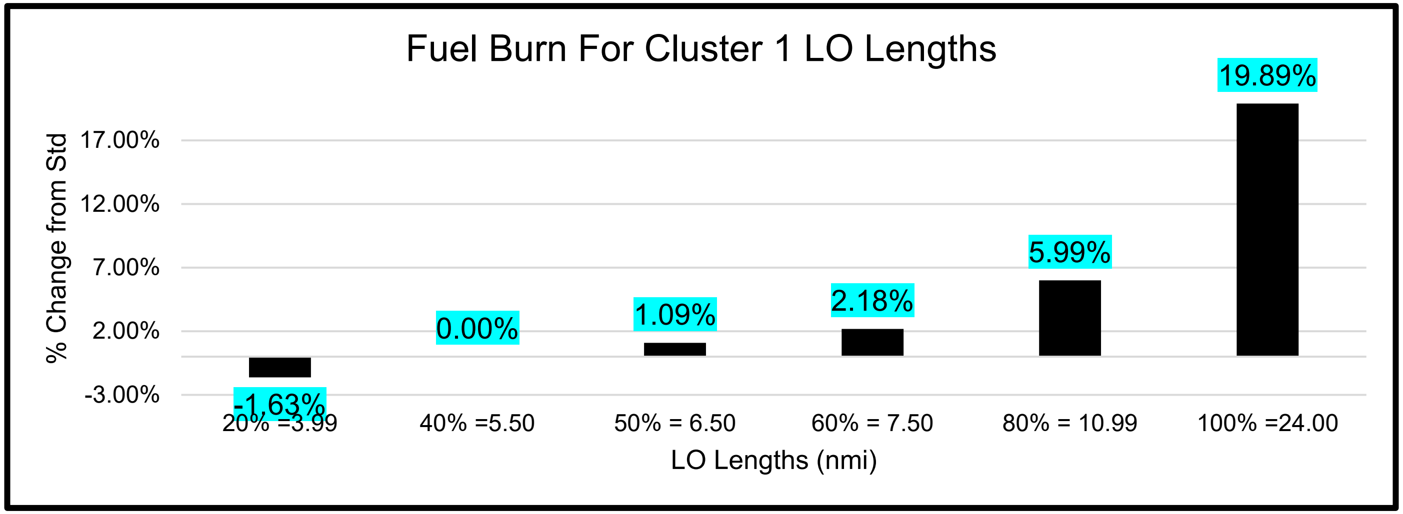
Arrival Modeling – Fuel Burn and Emissions visualizations

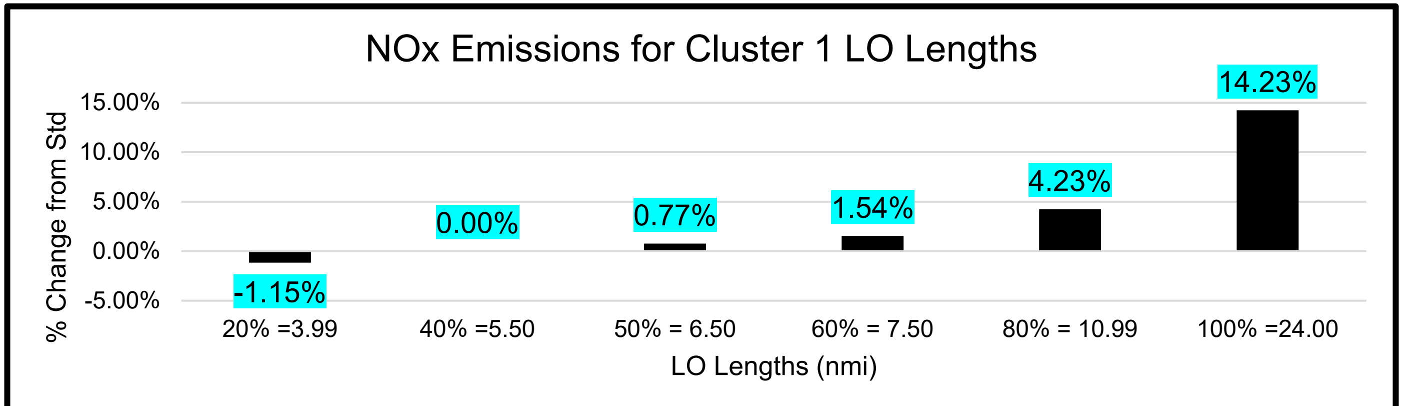




- Level-off heights for Cluster 1 have a higher influence on fuel burn and NOx emissions than the standard
- The emissions increase by 2-4% from the 20%ile LO heights profile

Arrival Modeling – Fuel Burn and Emissions visualizations





- In contrast to the fuel burn and NOx plots for LO height, here we can see for low LO lengths, an equal or reduction in the emissions than standard
- The emissions are slowly increasing up to 17.79 nmi which provides highest change in emissions

Arrival Modeling – Noise Contour Areas

LO Height (ft)	SEL Contour Area (sq mi)			
	75 dB	% Change from Std	70 dB	% Change from Std
20th Percentile = 7400	13.63	-0.72%	30.88	-9.94%
40th Percentile = 8200	13.62	-0.83%	30.97	-9.69%
50th Percentile = 8800	13.60	-0.91%	31.01	-9.57%
60th Percentile = 9300	13.59	-0.99%	31.04	-9.49%
80th Percentile = 9500	13.59	-1.02%	31.04	-9.47%
100th Percentile = 10000	13.58	-1.09%	31.06	-9.41%
Standard	13.73		34.29	

- No difference seen in contour areas for 80 dB SEL and above
- For these higher dB levels, all profiles are converged onto the same configuration & trajectory

Arrival Modeling – Noise Contour Areas

LO Length (nmi)	SEL Contour Area (sq mi)			
	75 dB	% Change from Std	70 dB	% Change from Std
20th Percentile = 3.99	13.69	-0.29%	31.75	-7.41%
40th Percentile = 5.50	13.73	0.00%	34.05	-0.70%
50th Percentile = 6.50	13.74	0.07%	35.57	3.73%
60th Percentile = 7.50	13.76	0.22%	37.01	7.93%
80th Percentile = 10.99	13.83	0.73%	42.36	23.53%
100th Percentile = 24.00	14.05	2.33%	62.22	81.45%
Standard	13.73		34.29	

- This table consists of contour areas for Level-off Length profiles
- The % change with respect to STANDARD increases with increasing Level-off lengths

Arrival Modeling – Next Steps

- Deeper dive into procedural profile definitions in AEDT
  - Develop a method to define generic CDO and Level-Off arrival profiles
  - Translate these profiles into procedural profiles for all relevant aircraft in the ANP database
- Analysis of newly obtained real-world data (Threaded Track & FOQA)
  - Analyze flap & gear transitions to ensure that they are accurately reflected in AEDT's procedural profiles
- Revisit the high-level objectives and develop arrival profile recommendations for AEDT

Task 2 – NPD+C Development

- Efforts from A43 were rolled into A54 this past year
- A43 focus is how to extend noise power and distance data (NPD+C) beyond the default arrival NPDs provided by manufacturers to account for changes in speed, flap, and gear settings, especially at lower thrust levels
- Current progress:
  - Simplified the correction function to only consider speed, flaps, and gear
  - Generating data for review by a manufacturer on the sensitivity of SEL to speed and flap settings
  - Benchmarking new approach to impacts on a single event noise contour
- Next steps:
  - Complete the current project and develop new correction functions, if results seem reasonable
  - Begin to outline an implementation scoping document for the AEDT developers

Full Flight Modeling

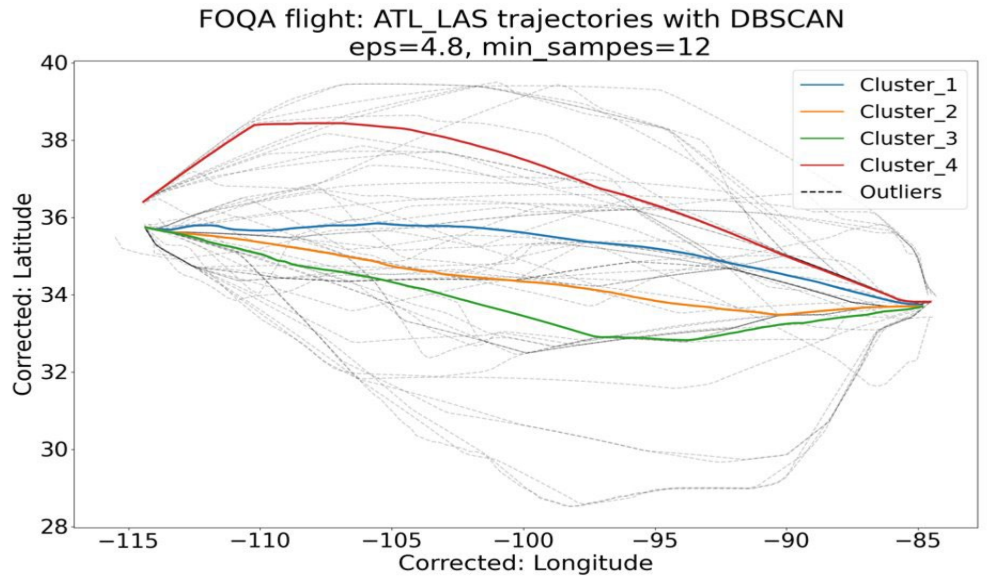
- Objective: Conduct full flight modeling in AEDT without the use of sensor paths to investigate the accuracy of performance modeling in AEDT compared to actual airline flight data, which includes all aircraft states (thrust, weight, and fuel flow)
  - Evaluate current AEDT full flight modeling features using sensor path inputs and propose an alternative "rapid" route analysis method, if appropriate, for general AEDT use
  - Identify potential causes of fuel flow anomalies when using the BADA4 performance models paired with MERRA-2[1] weather data

1 MERRA-2: Modern-Era Retrospective Analysis for Research and Applications, version 2

Full Flight Modeling – Previous work

- Initial Approach
  - Use data clustering methodologies to identify Flight Operational Quality Assurance (FOQA) data for core routes
  - Compare the results of the FOQA clustering to AEDT performance report output (flight time, fuel burn, and wind histories)
  - Often complicated and time-consuming process of using the sensor path functionality

Example of "core" route determinations using clustering methodology



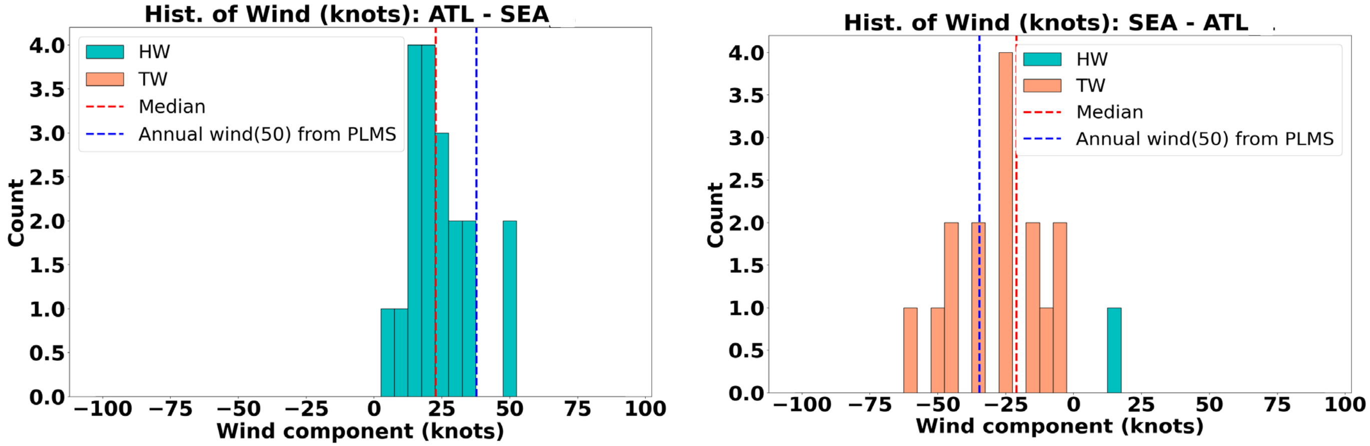
- Current Approach: Analysis of the FOQA core routes based on a notional range of Great-Circle Distance + %

Full Flight Modeling – Previous work

- Great-Circle Route Planning
  - Performed sensitivity analysis of trip distances/average wind distribution by generating histograms based on the FOQA routes identified
  - Comparative data source derived from the PaceLab Mission Suite (PLMS) commercial software product

Standard for the wind components for the analysis:

+ = Headwind, - = Tailwind



- Key observations
  - Great-circle distance + 3% variance is the closest to the median trip distance of the FOQA flights within the cluster
  - Wind conditions during the flight greatly affect the trip equivalent still air distance (ESAD) and vary significantly depending on flight direction

Full Flight Modeling – Current Approach

- Alternative methodology: seasonal wind model
  - A simplified route based on seasonal wind averages could enable an alternative approach to provide statistically valid predictions for time and fuel. This task aims to develop a weather model representing seasonal averages compatible with AEDT.
- Investigate the causes of fuel flow anomalies by analyzing the fuel flow rates and other related parameters

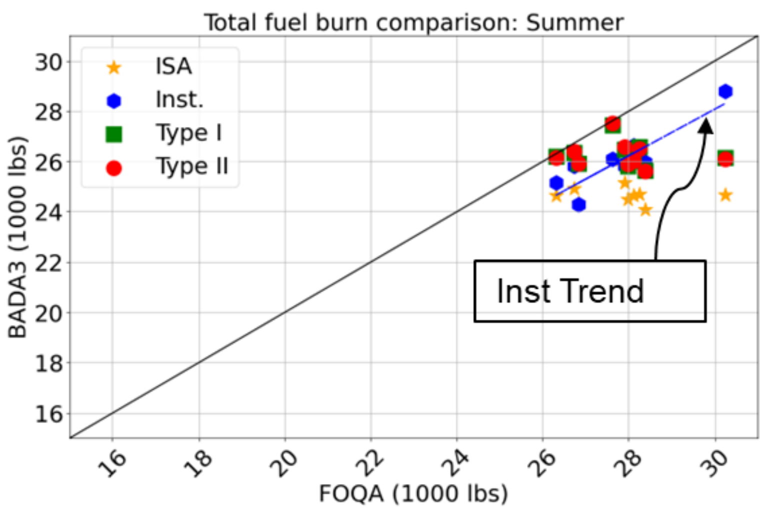
Alt. Methodology: Seasonal Wind Model

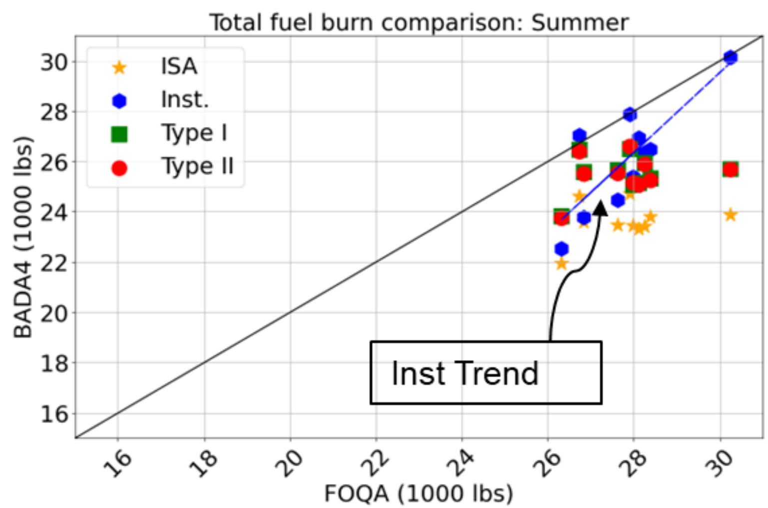
- Collect MERRA-2 weather data (i.e., instU_3d_asm_Np.nc4) and use it to create a seasonal wind model via Python code
  - Winter: December, January, and February
  - Spring: March, April, and May
  - Summer: June, July, and August
  - Fall: September, October, and November
- Two types of the seasonal wind model
  - Type I seasonal weather data, considering the time frame, time(8) X pressure level (42) x latitude x longitude
  - Type II seasonal weather data, disregarding the time frame, pressure level (42) x latitude x longitude

Alt. Methodology: Seasonal Wind Model

- Cumulative fuel burn comparison between AEDT modeling options (BADA3 / BADA4)
  - MERRA-2 instantaneous weather data matches FOQA flight data, showing similar fuel burn
  - ISA dataset underpredicts the fuel required for westbound flights (ATL-SEA) because due to lack of headwinds consideration (i.e., higher value of equivalent static air miles)
  - Minor differences arise with seasonal weather model types I and II

Example of cumulative fuel burn comparison using different weather types: ATL-SEA





* ISA: International Standard Atmosphere

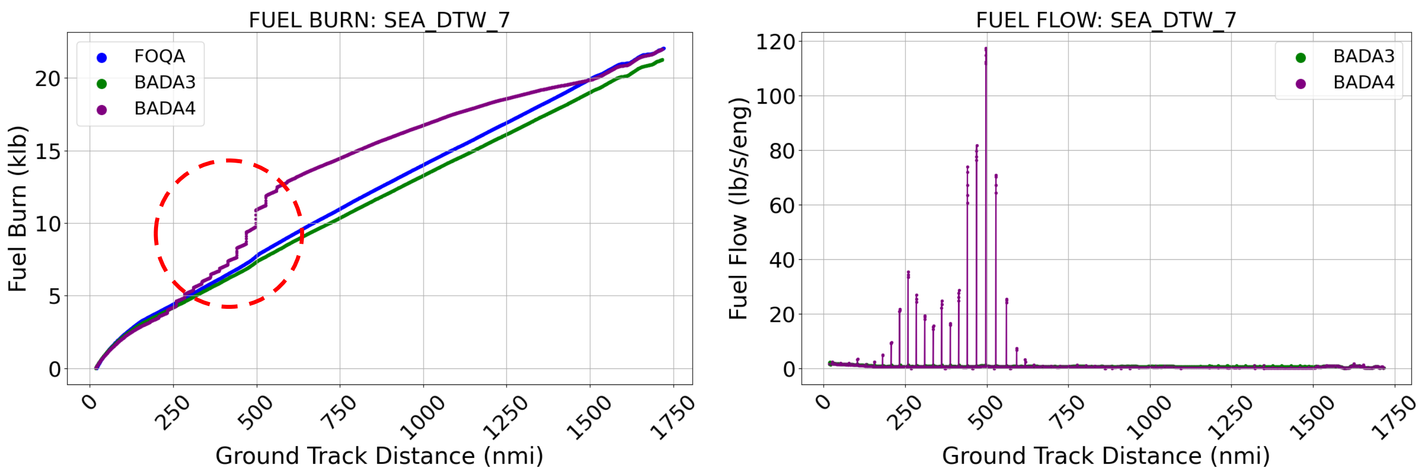
Inst.: MERRA-2 inst. weather data

Type I & II seasonal weather data

Investigation of the causes of BADA4 discontinuities

- Unrealistically high fuel flow rates were identified when using the BADA4 sensor path and high-fidelity MERRA-2 instantaneous weather data
- The issue was not found in results obtained using 1) BADA4 sensor path + ISA weather and 2) BADA3 sensor path + high-fidelity MERRA-2 instantaneous weather data

Example of unrealistically high fuel burn: SEA-DTW



- Down-sampling of the original trajectory data ('high-time resolution') helps resolve the BADA4 discontinuity issue
- Sharp changes in wind speed and direction over a short time are potential problems that can cause BADA4 discontinuities

Full Flight Modeling

- Findings to Date:
  - MERRA-2 instantaneous weather data matches FOQA data for similar fuel burn
  - ISA dataset does not consider the actual direction of winds
  - The fuel burn required from FOQA data may vary substantially depending on factors such as engine degradation and the status of engine maintenance
  - Need to examine the handling of weather data in AEDT to resolve the BADA4 discontinuity issue

- Next Steps:
  - Expanded validation of GCD + 3% model using additional available trajectory data, specifically threaded track data

Task 5 – Supersonic Modeling in AEDT

- As with A43, the A10 task of modeling SSTs in AEDT was rolled into A54
- The current framework within AEDT is based on the subsonic fleet and a new approach was needed for the unique flight characteristics of SSTs
- This task has developed a methodology to model a notional SST in AEDT, both terminal area and full flight modeling
- Created and provide a data pack to the developers to implement into AEDT
- Interacting with the AEDT developers to finalize the implementation plan

System Evaluation of AEDT Features

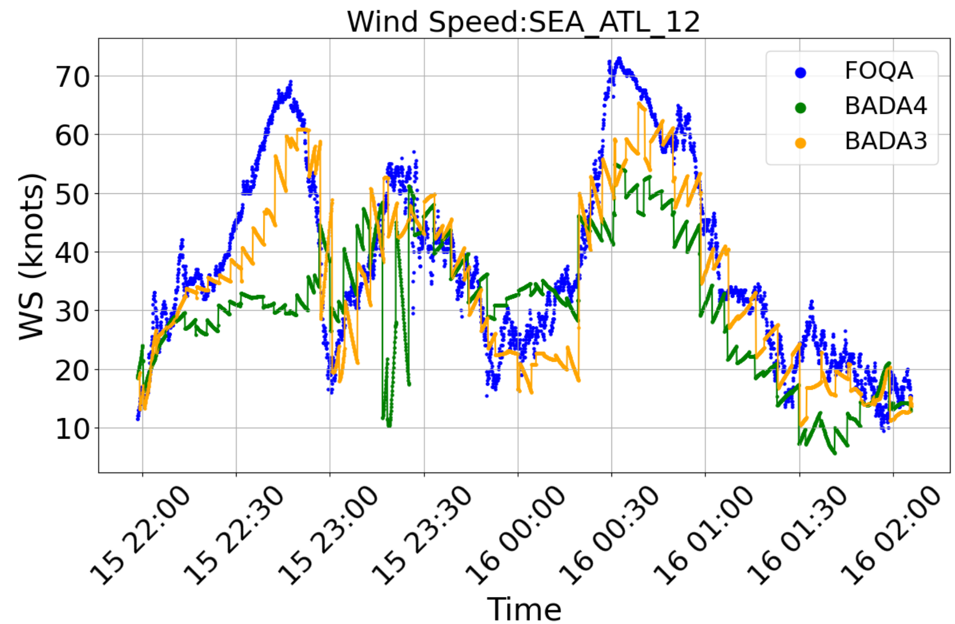
- **Objective**:
  1. Provide support to the AEDT continuous development process through system testing and evaluation
  2. Create comprehensive documentation of new features and capabilities in AEDT 3 for end users in the form of a UQ Report

- **Method**:
  - System testing is performed in accordance with test plans which are developed in conjunction with the AEDT Dev Team
  - Test results and identified bugs (if any) are reported to the Dev Team for resolution

Investigation into wind reporting anomalies

- Use case
  - OD pair: SEA – ATL
  - Aircraft type: B739
- Full flight modeling using trajectories from FOQA based on UTC[1]
- Using MERRA-2 instantaneous weather data
- AEDT 3e public release version 174.0.15710.1

Example of the problematic cases in wind reporting



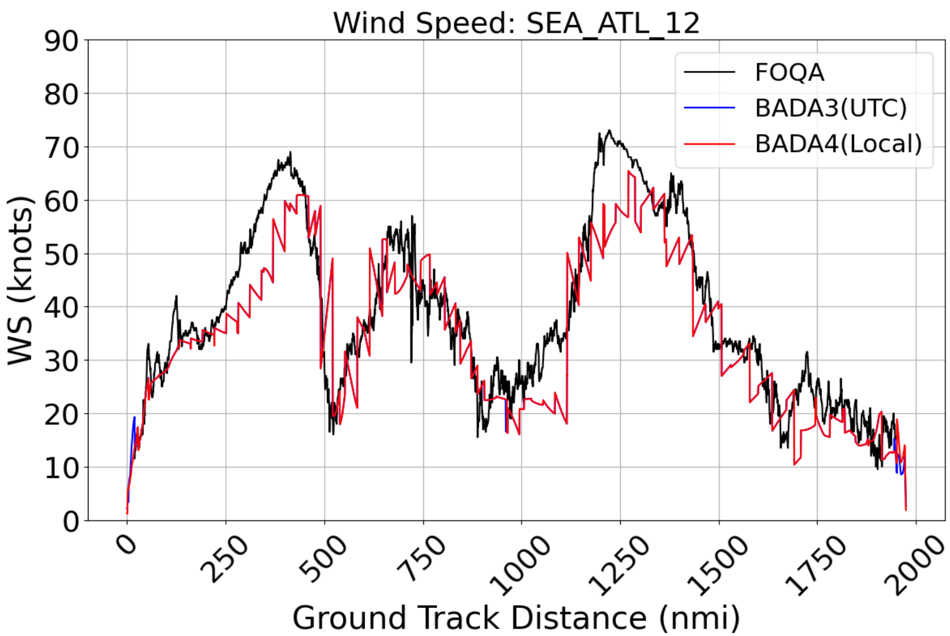
- BADA3 wind speeds are a closer match to FOQA wind speeds than BADA4
- Wind speeds reported in the RSLT_EMISSIONS_SEGMENT table do not match for BADA3 and BADA4

[1] UTC: Universal Time Coordinated

Investigation into wind reporting anomalies

- Use case
  - OD pair: SEA – ATL
  - Aircraft type: B739
- Define operation times in sensor path
  - BADA3 → UTC[1] (Blue)
  - BADA4 operations → local time at departure airport (Red)

Example of the problematic cases in wind reporting



- The identified discrepancy was reported to the AEDT Development team and will be fixed in the upcoming AEDT 3f release
- Improvements to accuracy of full-flight fuel burn and emissions inventories

[1] UTC: Universal Time Coordinated

Interfaces & Communications

- Outreach Efforts
  - Bi-weekly telecons with the FAA, Volpe, and ATAC
  - Attendance at bi-annual ASCENT meetings
  - Presentation at the annual Aviation Emissions Characterization (AEC) Roadmap meeting
  - Attendance at American Institute of Aeronautics and Astronautics (AIAA) SciTech & Aviation Conferences and OpenSky Symposium to present conference papers
- Contributors (team members)
  - FAA: Joe DiPardo (PM), Mohammed Majeed
  - Georgia Tech Research Faculty: Prof. Dimitri Mavris (PI), Dr. Michelle R. Kirby (Co-PI), Dr. Ameya Behere, Dr. Raphael Gautier
  - Georgia Tech Graduate Students: Jirat Bhanpato, Howard Peng, Hyungu Choi, Anushka S. Moharir, Archana Tikayat Ray
  - Volpe: Robert Downs, Eric Boeker, Stephen Goetzinger, Nicholas Bradley
  - ATAC: Denise Rickel

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Thank you!

Questions?